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The probabilistic planning approach: Including uncertainties into optimisation

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Any experiment, process or action in science aiming to be performed with high accuracy and precision requires a careful consideration of its underlying uncertainties and potential sources of errors.This most essential analysis plays a profound role in planning and evaluation of the considered processes and is based on established probabilistic concepts that quantify expectation values and variances of the quantities of interest.
Naturally, this general framework applies to the planning and evaluation of modern radiation therapy, where geometrical and dosimetric accuracy and precision are viewed as key performance indicators of a treatment. However, so far the analysis of potential treatment uncertainties is mostly limited to the PTV margin concept where only the aspect of dose coverage of the CTV is explicitly addressed at the early planning stage. This approach neglects dose uncertainties to other important tissues, because it heuristically accounts just for the expectation value of the prescribed tumor dose and furthermore does not provide any information about the variances or anticipated 'error bars' of any relevant treatment quality indicator.
The key idea of probabilistic treatment planning is to include the known or estimated uncertainties of treatment parameters, mostly described and modeled by Gaussian probability densities, directly into the treatment planning process and automatically generate dose distributions whose expectation value is 'robust', i.e. not sensitive to the anticipated inherent preparation and execution errors of the treatment. This requires sacrificing the PTV concept because respective safety zones for the dose of the tumor target will be automatically generated. Moreover, the method provides a complete analysis of the achieved dose patterns in terms of expectation values and their respective variances for a final evaluation of a treatment plan.
Besides a general introduction into the topic we will present various concepts of probabilistic treatment planning. A specific focus of the talk will be on a new approach of probabilistic analytical Gaussian dose calculations that allow an efficient application within standard inverse planning concepts. This approach is particularly well suited for planning of intensity modulated treatments with photon and proton beams and naturally can account for any correlation between the considered uncertainties. Several examples of respective treatments influenced by various sources of uncertainties will be discussed in detail.

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Exploiting daily imaging to assess margins taking deformations into account after daily set-up correction

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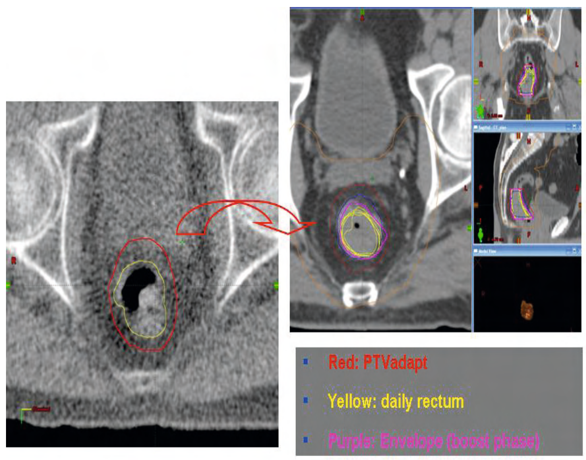
Modern image-guidance systems permit to efficiently correct set-up error through rigid translations and, in few cases, rotations of the patient. In the case of daily image guidance and disregarding contouring uncertainty, the margin that should actually be applied should take into account few residual components such as intra-fraction changes, the uncertainty of the IGRT system in assessing and applying the correction and the uncertainty due to the rigidity of the correction (here named: residual deformation error, RDE).
In several clinical situations, RDE is prevalent and, due to the difficulty in individually predicting GTV/CTV deformations during treatment, is difficult to manage and to rationally include in a properly defined margin. The scenario may also be influenced by shrinkage/progression of the tumour that may be counteracted by adaptive strategies. Even in this case, the problem of RDE is still there in the different phases of the treatment (before/after adaptive corrections).
When the contour of GTV/CTV is available on a large sample of fractions, the probability coverage map of the positions of GTV/CTV, after rigid correction, may be precisely assessed for each single patient: in the case of daily imaging, it represents the "true" coverage map. The local 3D distances between the planning GTV/CTV and the surface corresponding to a large probability coverage (SX%, typically S=90-100%) may be calculated to directly assess "margin maps" for each specific patient, intrinsically including systematic errors. Starting from this map, a pragmatic and robust approach is to split GTV/CTV into sectors (for instance, according to a spherical or a cylindrical system) and looking to the margin distribution in each sector. A first step is to consider the mean value of the local margins within each sector, defined here as the "smoothed sector margin" (SSM). If expanding GTV/CTV by SSM to take RDE into account in each sector, a fraction of the volume included in SX% is not included in the corresponding sector PTV ("Out-SSM volume", OSV): the impact of OSV depends on the spread of the local margins with respect to SSM (the SD of the variation of sector local margins). In order to take OSV into account, it is reasonable to define a cut-off value below which it may be disregarded (for instance 95 or 99% of the GTV/CTV sector volume): based on this, an additional margin (named "local-noise sector margin", LNSM) may be added to SSM to include the relevant fraction of OSV, according to this cut-off. LNSM may be negligible in many cases, depending on the noise of the local deformation, on the number/type of sectors and on the GTV/CTV volume. Patient specific SSM (and, if the case, LNSM) values may be pooled in a population analysis to derive SSMY% (and SSM+LNSMY%) corresponding to those values that may guarantee a large (90-100%) fraction of patient to be covered. The method was applied on a sample of 20 patients treated for rectal cancer (10 supine and 10 prone in institute A and B respectively), considering the motion of the rectum; the analysis was repeated for the whole and the second part of the treatment. Rectum was split in two halves (cranial-caudal) and each half was split in 4 equi-spaced sectors, according to a cylindrical segmentation of the rectum (in total 8 sectors). SSM corresponding to 90% and 100% coverage probability were derived for each sector of each patient; then, SSM90% (SSM assuring 90-100% sector coverage in 90% of the patients) were derived. For the supine group SSM90% were significantly smaller in the second part of the treatment with respect to the first one and were in the range 4-7mm. The consistency of SSM definition was prospectively confirmed on 20 additional patients treated with an adaptive boosting in the last 6 fractions (Figure 1): PTV including RDE was adequate for 10 male patients, while was slightly insufficient for 2/10 female patients.The suggested method can assess population-based margins taking RDE into account; it may robustly works especially in the case GTV/CTV or their surrogates may be drawn on already available daily in-room CT images.

Figure 1



SYMPOSIUM: PROTON DOSIMETRY

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Absolute dosimetry in proton therapy

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Purpose: Besides the need for consistent dosimetry of proton therapy beams worldwide, the measurement of absolute dose for this modality is important for a variety of reasons. Ensuring consistency with other treatment modalities is particularly important when performing mixed treatments such as proton and x-ray therapy as is being applied in some hospitals. Consistency with other forms of radiotherapy is evenly important for coherent detector perturbation factors and biological weighting factors across modalities.
Methods: The traditional method for measuring the quantity absorbed dose according to its definition is calorimetry. No primary standards for proton dosimetry currently exist although a number of national metrology institutes in Switzerland, Germany, The Netherlands and the United Kingdom are working towards such calorimetry-based